Retrieval of cloud emissivity and particle size in the frame of the CALIPSO mission

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***Abstract*—The retrieval of radiative properties of cold clouds at the global scale is an important challenge for the understanding of climate change. Amongst other objectives, the Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO) mission, developed in collaboration between NASA and CNES - planned to be launched in 2004 -, aims at improving our knowledge of semi-transparent cold clouds. Cloud emissivity and particle size will be retrieved using combined measurements from an infrared imaging radiometer (IIR) developed in France and a backscatter lidar developed in the USA. The concept of the instrument and the algorithm principle are presented. Synergism between lidar and IR radiometer instruments is discussed in the frame of the algorithm development.**

Keywords-clouds properties; lidar; IR radiometer; space mission

I. INTRODUCTION

The CALIPSO mission is developed in the frame of a collaboration between NASA Langley Research Center (LaRC), the French Centre National d'Etudes Spatiales (CNES), Hampton University (HU), the Institut Pierre Simon Laplace (IPSL) and Ball Aerospace and technologies Corporation (Ball). The objectives of this 3-year mission are to allow a better understanding of aerosol and cloud radiative forcing through the use of a combination of active and passive instruments defining the payload.

The CALIPSO mission, which launch is currently scheduled mid-November 2004, will fly a 2-channel polarization sensitive lidar (CALIOP) operating at two wavelengths (1064 and 532 nm) and allows cross-polarization measurements at 532 nm. A 3-channel Imaging Infrared Radiometer (IIR) developed in France by SODERN and CNES and a Wide Field Camera (WFC) operating in the visible domain will provide correlated measurements co-aligned with the nadir viewing lidar.

CALIPSO will fly in a sun-synchronous orbit as part of the A-train : Aqua (launched in May 2002), Cloudsat (co-manifested with CALIPSO), AURA (January 2004) and PARASOL (2005) a CNES microsatellite embarking POLDER, reinforcing the synergism to better address the objectives.

II. THE CALIPSO IMAGING INFRA-RED RADIOMETER

A. Instrument

The 3-channel IIR will make measurements in the thermal IR atmospheric window, at 8.65 µm, 10.6 µm and 12.05 µm. Spectral bandwidths of 0.85 µm, 0.6 µm and 1 µm, respectively, allow for a good separation of the signatures by semi-transparent clouds in the three spectral channels. The filters are disposed on a filter wheel providing sequential acquisition in a staring configuration. The unique sensor is a noncooled microbolometer array developed by Boeing. An effective area of 64x64 pixels has been selected to provide a 1-km resolution over the nadir observed scene. Intrinsic 1-sigma noise is equivalent to 0.2 to 0.3 K for the 3 channels for a scene temperature of 210 K and drops to 0.1 K for a 250 K scene temperature.

B. Calibrated radiances

A first calibration of the radiances has been made by IPSL/LMD and SODERN before the launch to provide spectral response knowledge, geometrical characterization and radiometric budget assessment. They have been done in a vacuum chamber, with relative channel and inter-pixel calibration, control of thermal behavior and linearity verification. During flight an on-board calibration will also be performed from sequential views of a temperature-monitored warm black body source (at about 295K) and cold deep space (4 K) views to monitor respectively gain and off-set of the detection system. Black body and deep space views will be performed every 40 s and 8 s respectively. Expected absolute calibration error is ± 0.3 K for all channels.

Level 1 processing uses these calibration data to provide 3 calibrated radiances over a 64-km swath which are registered on a reference grid centered on the lidar ground track, with 1 km horizontal resolution. Geo-location will be checked using contrasted scenes such as coastlines or islands with respect to reference maps. Calibration will be verified through consistency checks and direct comparisons with an airborne CALIPSO simulator and space measurements such as MODIS on Aqua (and Terra) or SEVIRI flown on Meteosat Second Generation. High spectral resolution infrared spectrometers may be used to verify spectral calibration stability.

III. CLOUD EMISSIVITY AND PARTICLE SIZE RETRIEVAL

The split window technique has long been applied to the data of spaceborne passive thermal imagers to retrieve the effective diameter of ice crystals in high altitude clouds [1], [2]. The implementation, in the frame of the CALIPSO mission, of an imaging infrared radiometer, a backscatter lidar and a camera operating in the visible spectrum on the same platform allows to go beyond limitations of passive sensors by taking advantage of the combination with active laser sounding. Use of polarization sensitive backscatter lidar data as inputs of the IIR inversion algorithm will allow to select analysis cases and to improve retrievals with a better knowledge of the parameters identified as a requirement for the inversion.

Analysis is conducted for all types of stratiform clouds which can be identified as single or multiple layered structures by the lidar. The algorithm first computes emissivity of such clouds for the 3 channels, then builds a generic microphysical index which leads to particle size retrieval through specific look-up tables (LUTs). These LUTs are providing values for different crystal shapes. There is selected additional information such as linear depolarization to constraint the retrieval (Fig. 1).

The type of scene observed under the lidar track is well described by the lidar, able to tell about the number of cloud layers, their top and bottom altitude, opacity, optical thickness or depolarization ratio [3]. The best analysis performances are expected from cases with 1 single layer semi-transparent thin cloud (such as a cirrus) or with a semi-transparent thin cloud over a dense homogeneous cloud identified as opaque by the lidar. Thick clouds, bi– and tri-layers systems require specific lidar inputs such as the extinction profile.

IIR inversion or core processing is first applied to the central pixels co-located with the lidar ground track. The retrieval is then extended over the IIR swath according to the scene homogeneity as observed by the wide field camera operating in the visible spectrum and by checking the cloud fraction and surface homogeneity.

A. Effective emissivity

For each spectral channel k, centered on the wavelength λ_k, the effective emissivity, $\varepsilon_{eff,\,k}$ of a thin semi-transparent cloud with top altitude Zc is defined as :

$$\varepsilon_{eff,\,k} = [R_k - R_{k,BG}]/[B_k(T,Z_c) - R_{k,BG}]. \quad (1)$$

In (1), R_k is the calibrated radiance measured in channel k, $R_{k,BG}$ is the outgoing top of the atmosphere background radiance which would be observed in the absence of the studied cloud (this reference background radiance corresponds to clear sky radiance in case of single layer systems) and $B_k(T,Z_c)$ is the radiance of a black-body source located at the reference altitude Z_c corresponding to a temperature T using ancillary meteorological data.

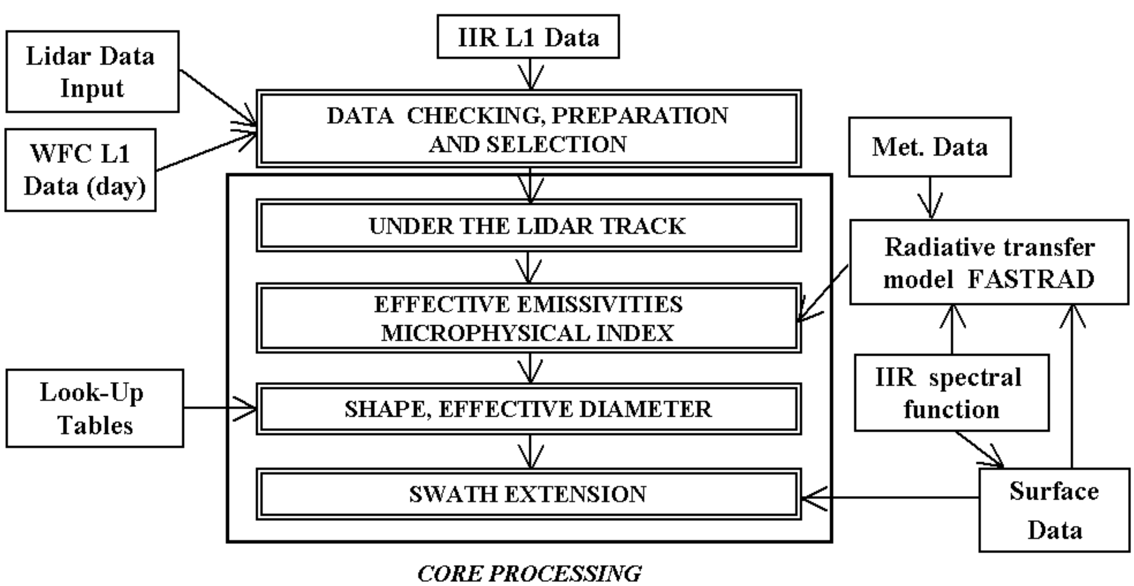

Figure 1. Algorithm flow diagram

If the lidar cannot allow to identify any background reference condition in the vicinity of the studied cloud, the reference radiance $R_{k,BG}$ will be computed with the radiative transfer models FASRAD or FASDOM adapted for the CALIPSO mission [4]. Besides the CALIPSO transfer functions in the 3 spectral channels, the model requires the knowledge of surface conditions (emissivity and temperature) together with water vapor and temperature vertical profiles. Surface emissivity will be determined from the surface type as given in the frame of the International Geosphere Biosphere Program (IGBP) and modified for the NASA's Cloud and earth's radiant Energy System (CERES) [5]. Snow and ice surface coverage is added as a daily information. Surface emissivities are computed for the 3 IIR spectral channels. Absorption by gases such as ozone, carbon dioxide, methane and N_2O is significant in the IIR channels and taken into account. In clear sky pixels radiative transfer calculations will be compared to measurements. Such pixels may be further used to refine the analysis of surface and aerosols during the mission.

B. Microphysical index

Absorption and scattering coefficients are related to the size distribution in clouds and to the shape of particles. It is now recognized that crystal shapes strongly affect scattering and absorption in cirrus clouds and need to be accounted for in a specific manner. A correction for scattering is made in the final steps in the retrieval algorithm, once the size and shape of particles are better assessed. Effective emissivities obtained in two IIR channels j and k allow to derive an effective microphysical index called $\beta_{eff,jk}$ defined in (2) as the ratio of the cloud effective absorption coefficients (including scattering) in those channels :

$$\beta_{eff,jk} = \mathrm{Ln}\,(1 - \varepsilon_{eff,\,j})/\mathrm{Ln}(1 - \varepsilon_{eff,\,k}). \tag{2}$$

Two microphysical indices are computed for both wavelength pairs 8.65 µm /12.05 µm and 10.6 µm /12.05 µm. Use of both microphysical indices allows to analyze the coherence between both wavelength pairs.

C. Particle size

Transfer functions are to be defined for different types of crystals to infer clouds properties from the microphysics index. They depend on size and shape of ice crystals and vary according to the IIR channel. The computation of cirrus cloud properties requires a precise knowledge of the single-scattering properties of non-spherical ice crystals [6]. A first sensitivity study using TOVS data at 8.5 µm and 11.3 µm has shown that the particle size retrieval can be affected by a few tens of percents depending upon the type of crystal assumed [7]. In addition to spheres, randomly oriented hexagonal columns and planar polycrystals are being considered to be included in the look-up tables relating microphysical index and particle size. Particle shape will be determined using the depolarization ratio as seen by the CALIOP lidar following the classification method described in [8]. Contribution of scattering is then taken into account to derive emissivity and ice water content. Several studies, including analysis of new field campaigns, are conducted within the IIR working group to assess performance of the retrievals and associated errors.

IV. CONCLUSION

A new algorithm relying on an improved split-window technique is being developed in the frame of the CALIPSO mission pre-launch activities to retrieve cloud microphysical properties. It is designed to be run in an production environment at the NASA LaRC Atmospheric Data Sciences Center for the analysis of space measurements. The algorithm will be validated and improved over the 3-year duration of the mission in the frame of validation dedicated and collaborative scientific campaigns. The development will be discussed by taking advantage of the synergy between available complementary measurements and platforms.

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